BASIC PROCESS CONTROL

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This document is an introduction to process dynamics and control for those who have little or no contact or experience with process dynamics. The objective is to illustrate where process control fits into the picture and to indicate its relative importance in the operation, design, and development of a process plant.

1. INTRODUCTION

Any study of process control must begin by investigating the concept of a "**process**". It is generally thought of as a place where materials and most often, energy come together to produce a desired product. From a control viewpoint the meaning is more specific. A process is identified as leaving one or more variables associated with it that are important enough for their values to be known and for them to be controlled.

In order to understand the concept, let us consider an example of a heat exchanger in which a process stream is being heated by condensing steam. The process is sketched in Figure 1.1. The purpose of this unit is to heat the process fluid from its inlet temperature $T_i(t)$, to a certain desired outlet temperature, T(t). As mentioned, the heating medium is condensing steam. The energy gained by the process fluid is equal to the heat released by the steam, provided there are no heat losses to the surroundings.

In this process there are many variables (e.g. Temperature of inlet stream, flow rate etc) that can change, causing the outlet temperature T(t) to deviate from its desired value. If this happens some action must be taken to correct this deviation. This defines the control objective of the process to maintain the outlet process temperature at its desired value.

One way to accomplish this objective is to measure the outlet temperature T(t), compare this value to the desired value, and, based on this comparison, decide what to do to minimize the deviation. The steam flow rate can be used to correct for deviation. That is, if the temperature is above the desired value, the steam valve canbe closed a little bit to cut the steam flow (energy) to the heat exchanger. If the temperature is below the desired value, the steam valve could be opened a little bit to increase the steam flow (energy) to the exchanger.

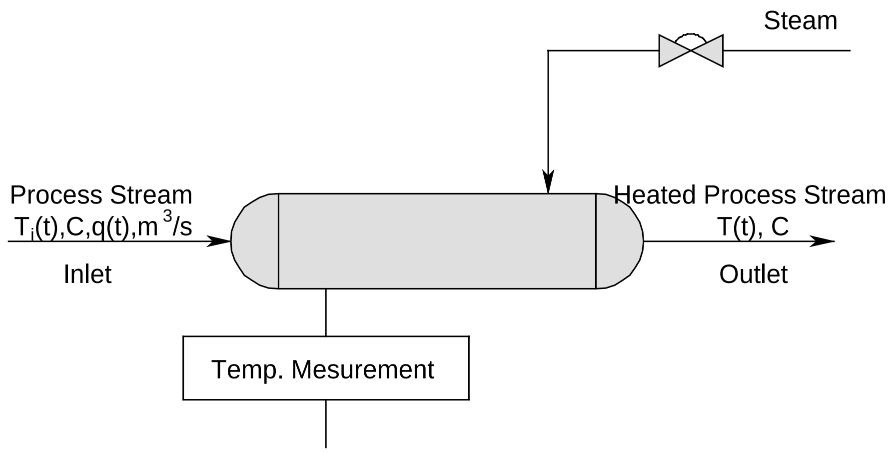

Figure 1.1: Heat Exchanger

Since all these can be done manually by an operator, and the procedure is fairly straightforward, it should not create any problem. But in most of the process plants, there are hundreds of variables that must be maintained at some desired value, in that case, this correction procedure requires large number of operators, which is not economically viable. Hence, we will like to accomplish this control automatically. That is we want to have instruments that control the variables without requiring intervention from the operator. That is what we mean by AUTOMATIC PROCESS CONTROL and the devices, which decide what control action should be taken, are called CONTROLLERS.

Laws of Process Control

First Law:

The simplest control system that will do the job is the best. Complex elegant process control systems look great on paper but soon end up on "manual" in an industrial environment. Bigger is definitely not better in control system design.

Second Law:

You must understand the process before you control it.

2. GENERAL CONCEPTS / TERMINOLOGY

2.1 Process Dynamics

It is concerned with analyzing the dynamic (i.e., time dependent) behavior of a process in response to various types of inputs. In other words, it is the behavior of a process as time progresses. Depending on the type of the process, the dynamic response could be different for the same input.

Open loop Response

The behavior where controllers are not present in the system is called ***open loop response***. (In fact, controllers can be present but they are not taking any action depending on feedback from the process.)

Closed loop Response

The dynamic behavior with feedback controllers (We'll see the meaning in following sections) controlling the process is called the ***closed-loop response.***

2.2 Types of Process Variables

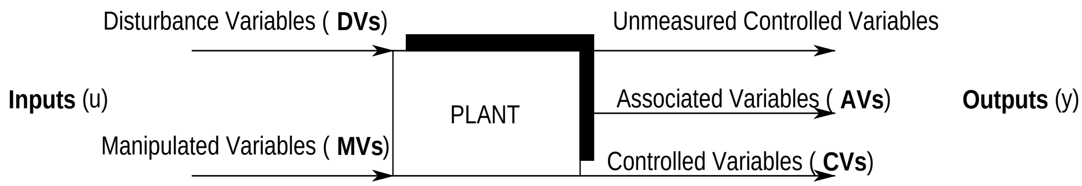

Figure 1.2: Definition of Input and Output Variables for Control System Design

Manipulated Variables (MVs)

The variables in a process that we can change in order to control the plant.

Disturbance Variables (DVs)

Flow rates, temperatures, or composition of streams entering (or sometimes leaving) the process. We are not free to manipulate them. They are set by upstream or downstream parts of the plant. The control system must be able to keep the plant under control despite the effects of these disturbances.

Inputs

MVs and DVs are collectively termed as Inputs to the process

Controlled Variables (CVs)

Flow rates, compositions, temperatures, levels, and pressures in the process that we control, either trying to hold them as constant at desired value or trying to make them follow some desired time trajectory.

Set–Point

The desired value of the controlled variable.

Associated Variables (AVs)

Are the output variables which have no target (Set – points) but have a bound.(Lower and upper)

Outputs

CVs and AVs together are referred as ***outputs***. Some of them are measured for feedback, while others are not.

Stability

Stability concerns the system's ability to converge or stay close to equilibrium.

Deviation Variables

A deviation variable is defined as the difference between the value of a variable or signal and its value at the operating point.

$P(t) = p(t) - p'$

Where

$P(t)$ is the deviation variable

$p(t)$ is the corresponding absolute value

p' is the value of x at the operating point (base value)

In other words, the deviation variable is the deviation of a variable from its operating or base value.

State Variables:

The minimum set of variables essential for completely describing the internal state (or condition) of a process. State variables are therefore the true indicators of the internal state of the process system. The actual *manifestation* of these *internal states* by measurement is what yields an *output*. Thus *output* variable is, in fact, some *calculated value* of either a single state variable or a combination of state variables.

For most processes, there are only three fundamental quantities: Mass, Energy and Momentum.

Quite often, the fundamental dependent variables cannot be measured directly and conveniently, and when grouped appropriately, they determine the value of the fundamental variables.

Thus Mass, Energy and Momentum can be characterized by variables such as density, concentration, temperature, pressure, and flow rate. These characterizing variables are called *state variables* and their values define the *state* of a system.

2.4 Degrees of Freedom

The degrees of freedom **(f)** of a process system are the independent variables that must be specified in order to define the process completely. (I.e. to determine the remaining process variables.) Consequently, the desired control of a process will be achieved when and only when all the degrees of freedom have been specified.

For a specified system, its mathematical model is the basis for finding the degrees of freedom under both dynamic and static conditions. To formulate control objectives and to design a control system, it is necessary to select the appropriate number of manipulated variables. In particular, the number of process variables that can be manipulated cannot exceed the degrees of freedom.

Degrees of freedom = (number of process variables) – (number of equations)

Case 1: Exactly Specified System (f = 0): unique solution

We have system of equations with equal number of variables. The solution of the E equations yields unique values for the V variables.

Case 2: Underspecified by f equations (f > 0): Infinite solutions

We have more variables than equations. Multiple solutions result from the equations since we can specify arbitrarily f of the variables. Here we need f additional equations to have a unique solution.

Case 3: Overspecified by f equations (f < 0): No solution. We have more equations than variables and in general there is no solution to the equations. In other words, we need to remove f equations to have a solution for the system.

2.5 Degrees of Freedom and Process Controllers

In general, carefully modeled processes will posses one or more degrees of freedom. Since for f > 0 the process will have an infinite number of solutions, the following question arises:

How do you reduce the number of degrees of freedom to zero so that you can have a completely specified system with unique behavior? It is clear that for an underspecified system with f degrees of freedom, we need to introduce f additional equations to make the system completely specified. There are two sources, which provide the additional equations:

The external world

By specifying the values of the disturbances, removes as many degrees of freedom as the number of disturbances.

The control system

Required to achieve the control objectives removes as many degrees of freedom as the number of control objectives.

2.6 Dead-Time or Time Delay

In most modeling examples, we assume that whenever a change takes place in one of the input variables (disturbances, manipulated variables), its effect is instantaneously observed in the state variables and the outputs.

The oversimplified picture given above is contrary to our physical experience, which dictates that whenever an input variable of a system changes, there is a time interval (short or long) during which no effect is observed on the outputs of the system. This time interval is called *dead time*, or *transportation lag*, or *pure delay*, or *distance-velocity lag.*

One final point of interest….

When we take up the issue of mathematical description of process systems, it is fairly common to represent the process variables as follows:

y – the output variable

u – the input(control) variable

d – the disturbance variable, and

x – the state variable (whenever needed)

3. GENERAL PRINCIPLES OF PROCESS CONTROL

Step 1: Assess the process and define control objectives.

The issues to be resolved in this step include the following:

(a) Why is there a need for control?

(b) Can the problem be solved only by control, or is there another alternative (such as redesigning part of the process)?

(c) What do we expect the control system to achieve?

Step 2: Select the process variables to be used in achieving the control objective articulated in Step 1.

Here we must answer the following questions:

(a) Which output variables are crucial and therefore must be measured in order to facilitate efficient monitoring of process conditions?

(b) Which disturbances are most serious? Which ones can be measured?

(c) Which input variables can be manipulated for effective regulation of the process?

Step 3: Select control structure.

What control configuration is chosen depends on the nature of the control problem posed by the process system. The usual alternatives are: Feedback, Feedforward, Open Loop (manual), Cascade, and others, which we shall discuss later.

Step 4: Design the controller.

This step can be carried out using varying degrees of sophistication, but it essentially involves the following: Obtain a control law (By a control law we mean a set of rules whereby the input to the process is transformed to its output) by which, given information about the process (current and past outputs, past inputs and disturbances, and sometimes even future predictions of the system output), a control decision is determined which the controller implements on process by adjusting the appropriate manipulated variables accordingly.

4. THE CONCEPT OF CONTROL

4.1 Motivation

The process control system is the entity that is charged with the responsibility for monitoring outputs, making decisions about how best to manipulate inputs so as to obtain desired output behavior, and effectively implement such decisions on the process. It is therefore convenient to break down the responsibility of the control system into the following three major tasks:

- Monitoring process output variables by ***measurement***
- Making rational ***decisions*** regarding what corrective action is needed on the basis of the information about the past(Integral action takes into account the past state of the process), current and desired state of the process
- Effectively ***implementing*** these decisions on the process

When these tasks are carried out manually by a human operator, we have a manual control system. A control system in which these tasks are carried out automatically by a machine is known as an automatic control system; in particular, when the machine involved is a computer, we have a computer control system.

4.2 Why process control?

Suppressing the influence of external disturbances: Disturbances are usually out of the reach of the human operator. Consequently, we need to introduce a control mechanism that will make the proper changes on the process to cancel the negative impact that such disturbances may have on the desired operation of a plant.

Ensuring the stability of a process: To ensure that, for every bounded input, a dynamic system produces a bounded output, regardless of its initial state.

Setpoint tracking: The control mechanism should be capable of making the process output track exactly any changes in the set point.

Optimizing the performance of a plant: It is desirable that a plant should always operate, at the point of minimum production cost or maximum profit. This can be achieved by an optimizing control strategy which:

- Identifies when the plant must be moved to a new operating point in order to reduce the operating cost.

- Make the appropriate set point changes to bring the plant to the new optimum operating point.

The above concepts can be explained using various examples in real life.

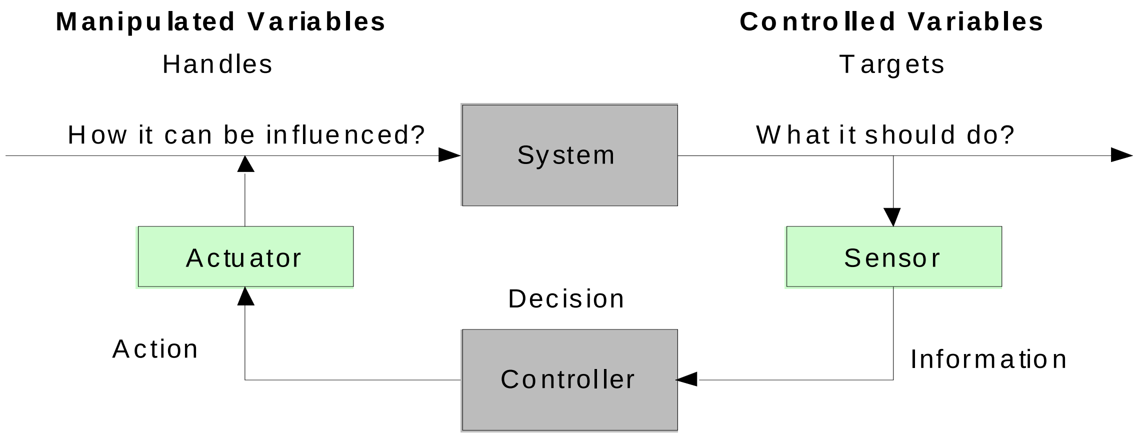

Figure 1.3: Concept of Process Control

TABLE 1.1: Control System Examples

System	CV	MV	Sensor	Actuator
Car	Direction Speed	Axle Position Fuel Flow	Human Speedometer	Steering Wheel Gas Pedal
Reactor	Product Quality Production	Temperature Feed Rate	Meters	Valves
Home	Lighting Temperature	Voltage Air Flow, Mix	Photoelectrics Thermostats	Dimmers AC Controls
DC Motor	Speed	Armature Current; Field Current	Tachometer	Armature resistance

5. BASIC COMPONENTS OF A CONTROL SYSTEM / CONTROL SYSTEM HARDWARE

There are four basic components of all control systems:

5.1 Sensor

- Also often called as Primary Element.
- Acquires information about the status of the process variables.
- Typical examples: thermocouples (for temperature measurements), differential pressure cells (for liquid level measurements), gas/liquid chromatographs (for composition measurement), etc.

5.2 Controller

- The "brain" or "heart" of the control system (the decision maker).
- It is the hardware element with "built-in" capacity for performing the only task requiring some form of "intelligence."
- Typical examples: Pneumatic controller, Electronic controllers, digital computers used as controller.

5.3 Transmitter

- Secondary Element.
- It has the responsibility of passing the information acquired by the sensor to controller and sending the controller decision to the final control element.
- Measurement and control signals may be transmitted as air pressure signals, or as electrical signals.
- Typical examples: Pneumatic transmitters, Electrical transmitters.

5.4 Final control element

- Have the task of actually implementing the control command issued by the controller on the process.
- Typical examples: often a control valve but not always. Other common final control elements are variable speed pumps, conveyors, and electric motors.

The importance of these components is that they perform the three basic operations that *must* be present in *every* control system. These operations are:

1. **Measurement (M):** Measuring the variable to be controlled is usually done by the combination of sensor and transmitter.

2. **Decision (D):** Based on the measurements and the set point, the controller must then decide what to do to maintain the variable at its desired value.

3. **Action (A):** As the result of the controller's decision, the system must then take an action. This is usually accomplished by the final control element.

The working principles of a control system can thus be summarized as "M, D, A":

M refers to the measurement of process variables

D refers to the decision to be made based on the measurements of process variables

A refers to the action to be taken based on the decision

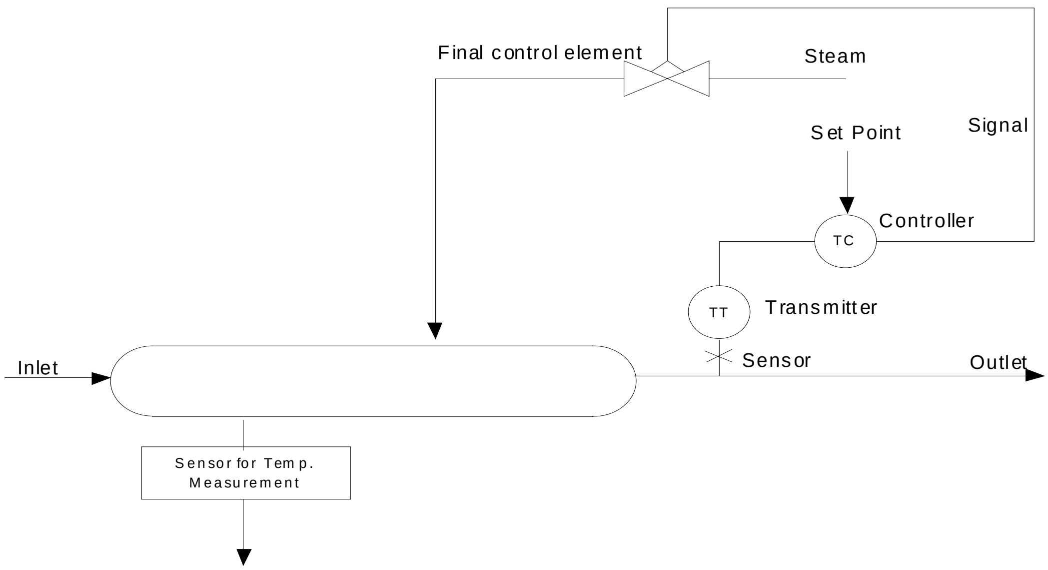

Figure 1.4: Heat Exchanger Control System

6. CONTROL SYSTEM CONFIGURATION

Depending primarily upon the structure of the decision-making process in relation to the information-gathering and decision implementation ends, a process control system can be configured in several different ways. Let us introduce some of the most common configurations.

6.1 Feedback Control

The traditional way to control a process is to measure the variable that is to be controlled, compare its value with the desired value (the setpoint) at the controller and feed the difference (error) into a controller, which will change a manipulated variable to drive the controlled variable back to the desired value.

Information is thus "fed back" from the controlled variable to manipulated variable, as sketched in Figure 1.5 so it is called Feedback control.

In other words, it uses direct measurements of the controlled variables to adjust the values of the manipulated variables.

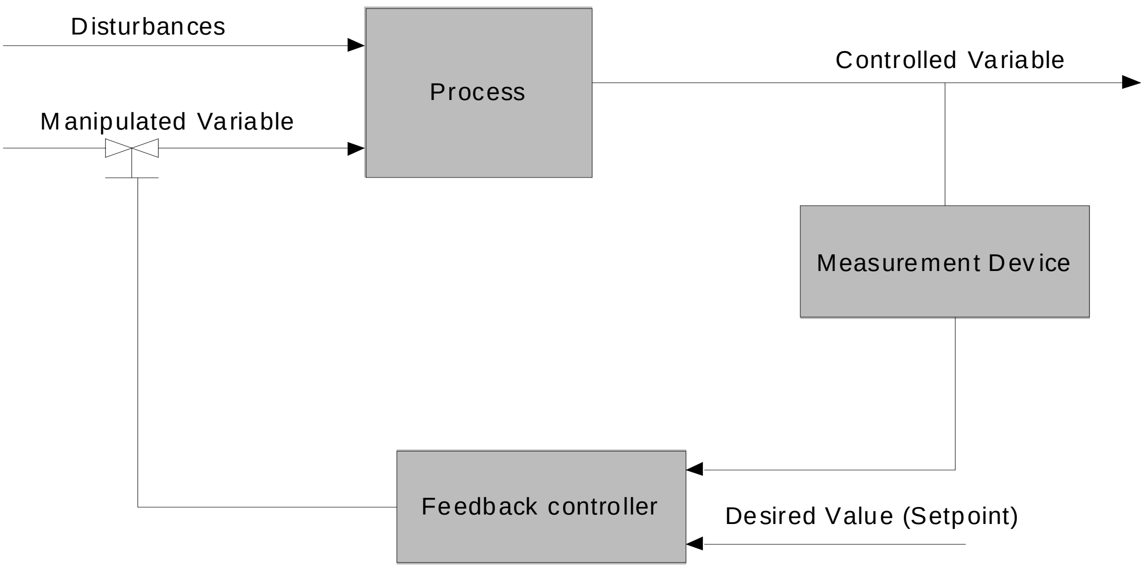

Figure 1.5: Feedback Control

Positive Vs Negative Feedback

Every feedback controller will have a means of changing the controller action; which defines the direction of the controller response to a change in the measurement. Increase-increase (or, direct) action causes the controller to increase its output in response to an increasing measurement. Increase–decrease (or, reverse) action causes the controller to decrease its output when the measurement increases. Choosing wrong action will make control impossible.

For a feedback loop to be successful, it must have negative feedback. The controller must change its output in the direction that opposes the change in measurement. Selecting the proper control action is as fundamental as a making sure the loop is truly closed. The wrong choice destroys control.

6.2 Feedforward Control

The basic idea is shown in Figure 1.6. Disturbances are detected as they enter the process and appropriate changes are made to the manipulated variable such that the controlled variable is held constant.

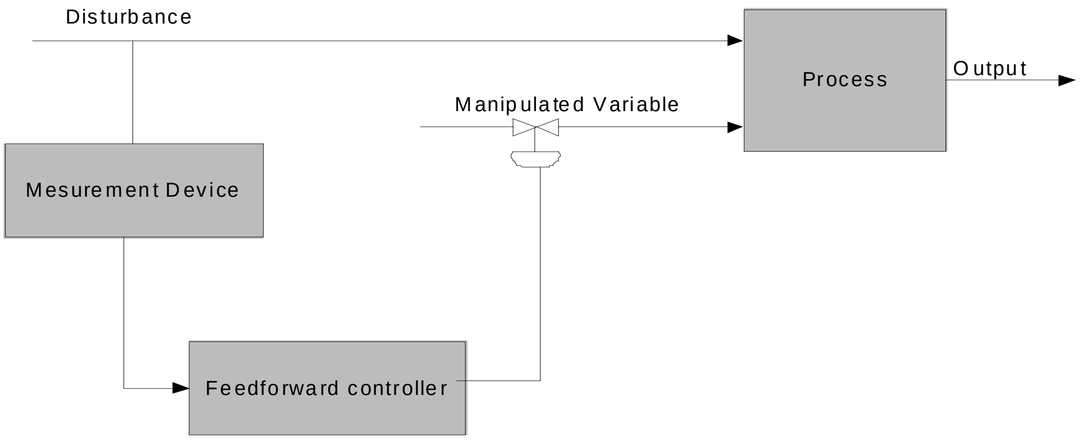

Figure 1.6: Feedforward control

Thus we begin to take corrective action as soon as a disturbance entering the system is detected instead of waiting (as we do with feedback control) for the disturbance to propagate all the way through the process before a correction is made.

6.3 Inferential Control Configuration

Uses secondary measurements (if the controlled variable cannot be directly measured) to adjust the values of the manipulated variables. (See Figure 1.7).

The objective here is to keep the (unmeasured) controlled variables at desired levels. The estimator uses the values of the available measured outputs together with the material and energy balances that govern the process, to compute mathematically (estimate) the values of the manipulated variables.

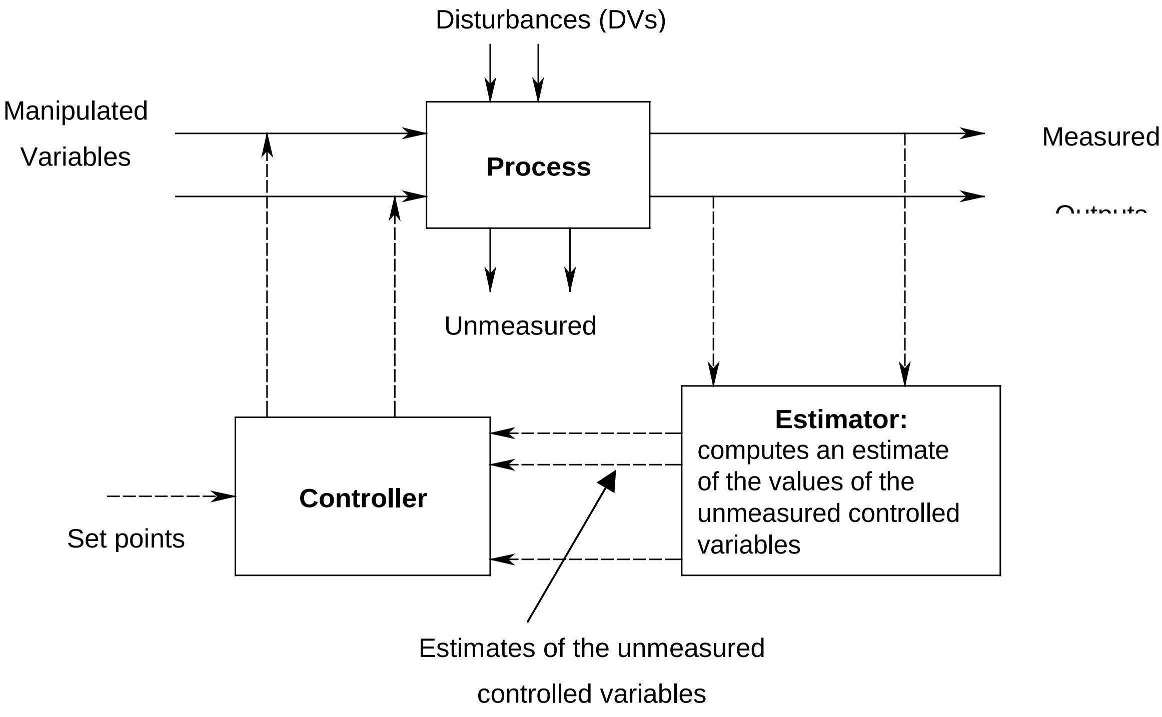

Figure 1.7: General structure of inferential control configurations

TABLE 1.2: Advantages and Disadvantages of Feedforward Control

FEEDFORWARD CONTROL	
Advantages	**Disadvantages**
1. Acts before the effect of a disturbance has been felt by the system 2. Is good for slow systems or with significant dead time 3. It does not introduce instability in the closed-loop response.	1. It requires the identification of all possible disturbances and their direct measurement, something that may not be possible for many processes. 2. Any changes in the parameters of a process (e.g. deactivation of a catalyst with time, reduction of a heat transfer coefficient due to fouling, etc.) cannot be compensated by a feedforward controller because their impact cannot be detected. 3. Feedforward control requires a very good model for the process to compute the outputs of the process for given inputs, which is not possible for many systems in process industry.

TABLE 1.3: Advantages and Disadvantages of Feedback Control

FEEDBACK CONTROL	
Advantages	**Disadvantages**
1. It does not require identification and measurement of any disturbance. 2. It is insensitive to process modeling errors. 3. It is insensitive to parameter changes (e.g. deactivation of a catalyst with time, reduction of heat transfer coefficient due to fouling, etc.).	1. It waits until the effect of the disturbance has been felt by the system, before control action is taken. 2. It is unsatisfactory for slow processes or with significant dead time. 3. It may create instability in the closed loop response.

7. A GENERALIZED VIEW OF THE PROCESS MODEL

The concept of representing process behavior with purely mathematical expressions is called modeling and the resulting form is called a model.

The most important model form in Process Dynamics and Control studies still remains the *transfer function* form, which we will see in next section. We will discuss some fundamental principles of how transfer functions are used for dynamic analysis.

7.1 Types of Models

7.1.1 State-space model

The input, u(t) , is a time-domain function, and the output, the time-domain function y(t) is generated by the process of solving differential or difference equations that model the process

7.1.2 Transfer-domain model

The input is u(s), a function of the Laplace transform variable s, and the output, y(s) (also a function of s), is generated by the process of multiplying u(s)by the function G(s).(G(s) is also called as TRANSFER FUNCTION)

7.1.3 Frequency-response model:

The input, u(jw) is a function of the indicated complex frequency variable, and the output y(jw) (also a function of the same variable), is generated by the process of multiplying u(jw) by the function G(jw).

7.1.4 Impulse-response model

The input, u(t) is a function of time, and the output, y(t) (also a function of time), is generated by a convolution operation of G(t) on u(t).

7.2 Concept of a Transfer Function (TF)

The underlying principles in each case discussed above may now be stated as follows: The function, by way of the indicated operation, “transfers” (or transforms) the input u(.) to the output y(.) as depicted in the equation:

$$y(.) = G(.)*u(.)$$

where * represents the particular operation demanded by the specific model form and G(.) represents the function employed for the “transfer” of the input u(.) to the output y(.) via the indicated operation. For any model form, the function G(.) that performs the noted task is called the "transfer function" of such a model form.

If we include the effect of disturbances:

$$y(.) = G(.)*u(.) + g_d(.) * d(.)$$

The transfer function is usually represented by:

G(s) = K [Y(s) / X(s)]

where

G(s) = the general representation of a transfer function

Y(s) = Laplace transform of the output variable

X(s) = Laplace transform of the forcing function or input variable

7.3 Poles and Zeros of a Transfer Function

With the exception of time-delay systems, G(s) is generally a ratio of two polynomials in **s**, i.e.:

$$G(s) = N(s) / D(s)$$

where the numerator polynomial N(s) is of order r, and the denominator polynomial D(s), is of order n.

For real processes, we note that r is usually *strictly* less than n.

If these polynomials are factorized as follows:

N(s) = K1 (s – z1) (s – z2) ……………(s – zr)

D(s) = K2 (s – p1) (s – p2)…………(s – pn)

hence

$$G(s) = K [(s - z_1) (s - z_2) \ldots\ldots(s - z_r)] /[(s - p_1) (s - p_2)\ldots\ldots(s - p_n)]$$

Where K = K1/K2

Note that:

For $s = z_1$, or z_2,…………,or z_r, $g(s) = 0$.

For $s = p_1$, or p_2…………..or p_n, $g(s) = \infty$

The roots of the *numerator* polynomial, N(s), i.e., z_1, z_2…………..,z_r, are thus called the ***zeros*** of the transfer function, while p_1, p_2,……..,p_n, the roots of the **denominator** polynomial, D(s), are called the transfer function ***poles***.

Some important properties of transfer functions

- In the TF of real physical systems the highest power of s in the numerator is never higher than that of the denominator. In other words, $r \leq n$.
- The TF relates the transforms of the deviation of the input and output variables from some initial steady state. Otherwise the nonzero initial conditions would contribute additional terms to the transform of the output variable.
- For stable systems the steady-state relationship between the change in output variable and the change in input variable can be obtained by:
  $\lim_{s \to 0} [G(s)]$

8. CLASSIFICATION OF DISTURBANCES

The variables over which we have no control are called disturbance variables. Disturbances may be measurable or unmeasurable. They are classified as:

8.1 Based on Shape of Disturbance (Also called Input Forcing Functions)

8.1.1 Step

Functions that change instantaneously from one level to another and are thereafter constant. The response of a system to a step disturbance is called the *step response* (or the *transient response*.)

8.1.2 Pulse

A pulse is a function of arbitrary shape (usually rectangular or triangular) that begins and ends at the same level.

8.1.3 Impulse

The impulse is defined as the Dirac Delta function, an infinitely high pulse whose width is zero and whose area is unity. This kind of disturbance, of course, a pure mathematical fiction, but we will find it as a useful tool.

8.1.4 Ramp

Ramp inputs are functions that change linearly with time.
Ramp function = Kt, where K is a constant.

8.1.5 Sinusoidal

Pure periodic sine and cosine inputs seldom occur in real systems. The response of systems to this kind of forcing function called the frequency response of the system and is of great practical importance.

8.2 Based on location of disturbance in feedback loop

8.2.1 Load disturbances

E.g. Changes in throughput, feed composition, supply steam pressure, cooling water temperature.
The feedback controller's function is to return the controlled variable to its setpoint by suitable changes in the manipulated variables. *The closed-loop response to a load disturbance is called the '**regulatory response'** or the 'closed loop load response.'*

8.2.2 Setpoint disturbances

These occur for, e.g. particularly in batch processes or in changing from one operating condition to another in a continuous process.

These setpoint changes also act as disturbances to the closed-loop system. The function of the feedback controller is to drive the controlled variable to match the new setpoint. *The closed-loop response to a set-point disturbance is called the '**servo response'**.*

9. LOW ORDER SYSTEMS

Systems which are characterized by transfer functions with denominator polynomials of order 1 or less are called low order systems.

9.1 First Order Systems

First order processes are described by the transfer function (described by a first order differential equation.): $G(s) = K/(\tau s + 1)$

Characteristic parameters of a first-order system may now be identified as K and τ, respectively called the ***steady-state gain*** and the ***time constant*** for reasons which shall soon be made clear.

The transfer function has a single pole at $s = -1/\tau$.

Time Constant (τ):

The time constant (τ) of a process is a measure of the time necessary for the process to adjust to a change in its input. The value of the response reaches 63.2 % of its final value when the time elapsed is equal to one time constant.

Time elapsed		τ	2τ	3τ	4τ
Response as % of its ultimate value	63.2	86.5	95	98	

Steady state / static gain (K)

K = (change in output) / (change in input)

Gain tells us: how much we should change the value of the input in order to achieve a desired change in the output.

9.2 Pure Gain Systems

Consider a first-order system with $\tau = 0$. The transfer function of such a process is identified as G(s) = K.

A process having such characteristics is referred to as a pure gain process by virtue of the fact that its transfer function involves only one characteristic parameter, K, the process gain term. Pure gain systems are always at steady state, moving instantly from one steady state to another with no transient behavior in between steady states.

The transfer function for pure gain systems has no poles and no zeros. The output of a pure gain process is *directly proportional* to the input, the constant of proportionality being the process gain. The pure gain system with the most important application in process control is the *proportional controller.*

Note:

$\tau = 0$ corresponds to a physical system that, theoretically, is infinitely fast in responding to input. More realistically, one might imagine a situation in which the first-order system is so fast in responding that τ is so small as to be negligible.

First-order or higher order systems whose dynamics are extremely fast may be conveniently approximated as pure gain processes.

9.3 Pure Capacity Systems

The TF of pure capacity process is given by G(s) = K*/s.
This system is characterized by the presence of the integrator (or capacitance) element 1/s and the parameter K*, which may be regarded as an integrator gain.

9.4 Lead/Lag System

The dynamic system whose transfer function is given by $G(s) = K(\xi s + 1)/(\tau s + 1)$ is known as a lead/lag system.
It is important to note that the main difference between this transfer function and that of the first-order system is the presence of the additional first-order numerator term. Otherwise, both functions have denominator polynomials of identical order.

Characteristic parameters of the lead/lag system are:

K	System gain
ξ	Lead time constant
τ	Lag time constant
$\rho = \xi/\tau$	"Lead-to-lag" ratio

The transfer function for the lead/lag system has one pole located at $s = -1/\tau$ and one zero located at $s = -1/\xi$.

Note: ξ is called the damping ratio. The definition is given in next section.

10. HIGHER ORDER SYSTEMS

Having discussed the behavior of low-order systems in the last session, the next level of complexity involves those systems modeled by linear differential equations of higher (but still finite) order. Such systems are typically characterized by transfer functions in which the denominator polynomials are of order higher than 1.

10.1 Two First-Order Systems in Series

Such systems can be configured in two ways:

10.1.1 Non-interacting system

Variation in one system does not affect the transient response in other. In Figure 1.8, tank 1 feeds tank 2 and thus it affects its dynamic behavior, whereas the opposite is not true. Such a system is characteristic of noninteracting system.

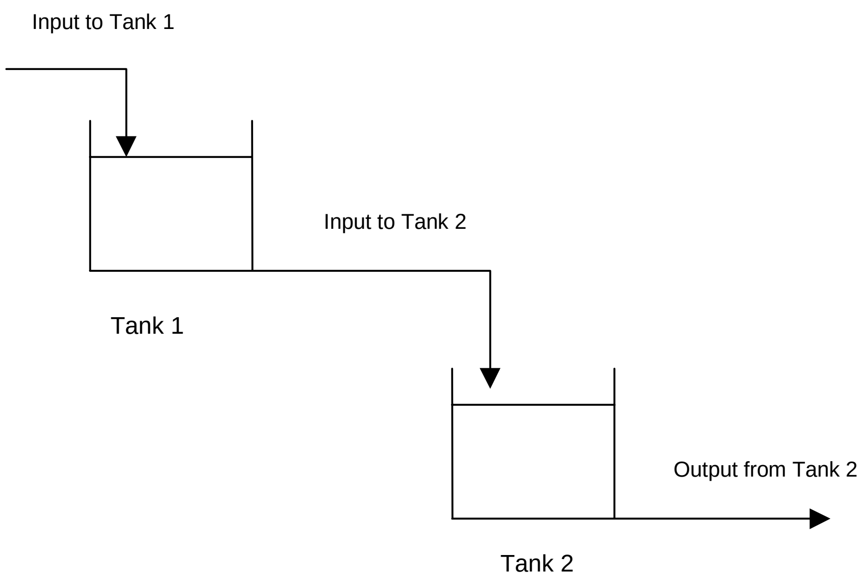

Figure 1.8: Non-interacting System

10.1.2 Interacting system

Variation in one system affects the transient response in other. In Figure 1.9, tank 1 affects the dynamic behavior of tank 2, and vice versa, because the flow rate F_1 depends on the difference between liquid levels h_1 and h_2. This system represents an interacting system.

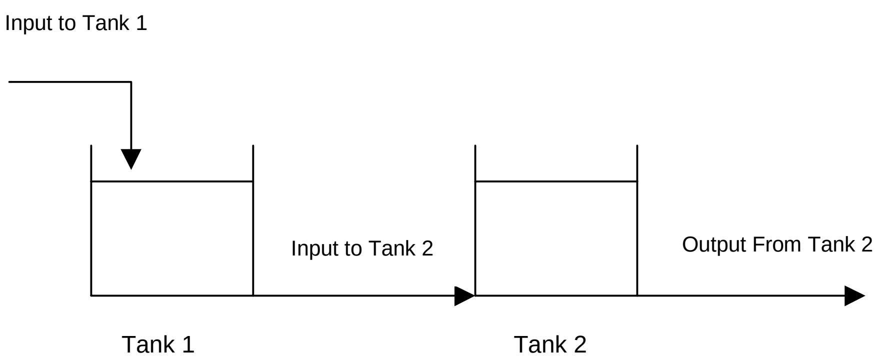

Figure 1.9: Interacting System

10.2 Second Order Systems

A general second-order system is described by the following differential equation.

$$\tau^2 (d^2y/dt^2) + 2\zeta\tau (dy/dt) + y = x(t)$$

Where,

τ Time Constant

ζ The damping ratio

The transfer function, Gp, for this system is

$$\frac{y(s)}{x(s)} = \frac{1}{T^2 s^2 + 2\varsigma T s + 1}$$

The roots of the characteristic equation (the denominator of the above equation) s1 and s2 can be real or complex depending upon the value of the damping constant.

(1) When ζ **< 1**, the roots s1 and s2 are complex so the system response is underdamped and oscillatory.

(2) When ζ **> 1**, the roots are real so that the system response is overdamped and uniformly monotonic.

(3) When ζ **= 1**, the system is critically damped.

The following terms are used to describe an underdamped (ζ < 1)-system response. These terms are illustrated in Figure 1.10.

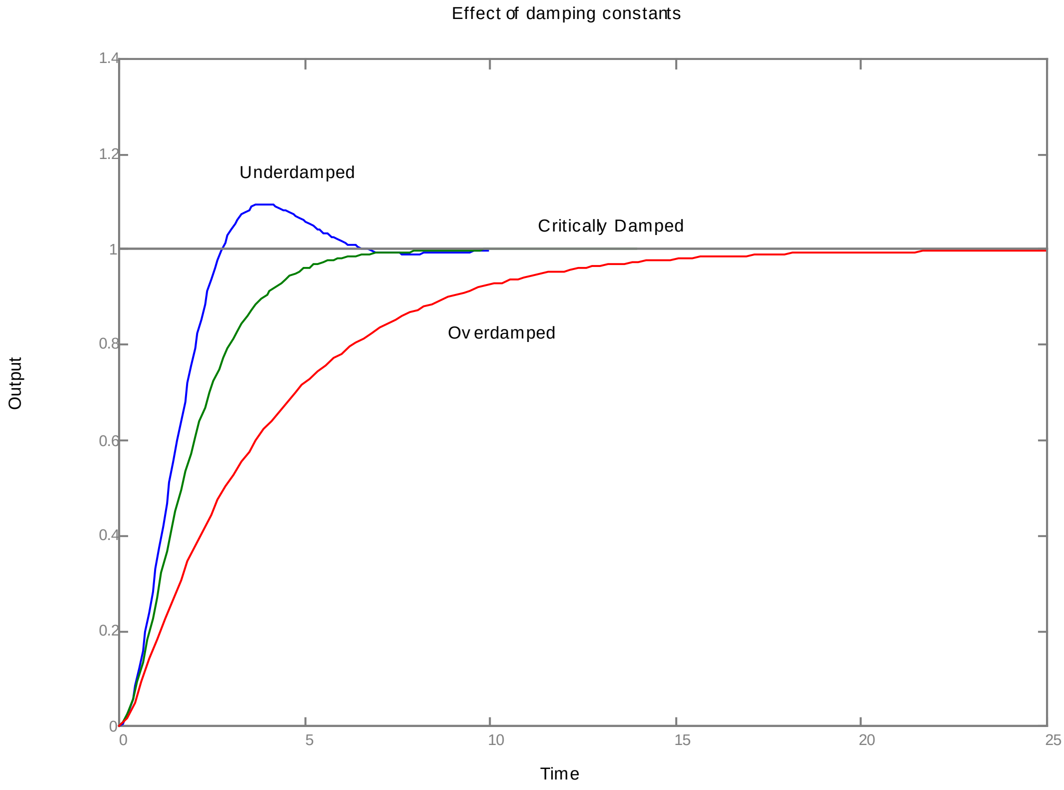

Figure 1.10: Characteristics of Second Order System

Characteristics of underdamped systems are as follows (ref: Figure 1.11):

Overshoot = (A/B)

The overshoot is the ratio of the maximum peak value to the desired steady-state value of the output variable.

Decay Ratio = (A/C)

This is the ratio of successive peak heights.

Rise Time = (tr)

The rise time is the time at which the system output first reaches the desired steady-state value.

Response Time = (td)

This is the time when the output variable gets to within a specified range, say ± 5 %, of the steady-state value and remains there.

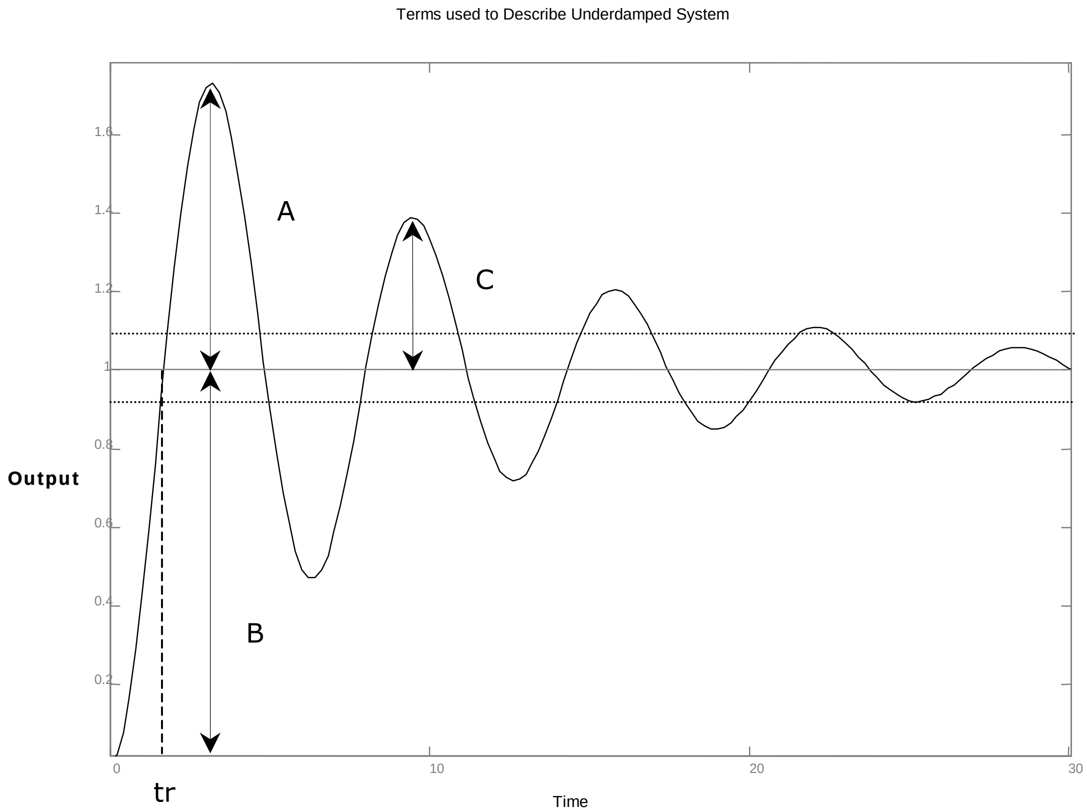

Figure 1.11: Characteristics of underdamped systems

10.3 The General Nth Order System

The combination of N first order systems in series gives the Nth order system. Here we have two situations:

- The roots are real(either distinct or multiple), or
- Some roots occur, as complex conjugates while the others are real.

The general Nth order system behavior is composed either entirely of the behavior of N first-order systems in series, or a combination of several underdamped second-order systems included in the series of first-order systems.

11. INVERSE-RESPONSE SYSTEMS

When the initial direction of a process system's step response is *opposite* to the direction of the final steady state, it is said to exhibit *inverse response.*

There is an initial inversion in the response of such processes that starts the process output heading *away* from its ultimate value; this is later reversed, and the process output eventually heads in the direction of the final steady state value. The system with an **odd** number of **RHP (Right Half Plane)**zeros exhibits **true** inverse response in the sense that the initial direction of the step response will always be opposite to the direction of the final steady state, regardless of the number of inversions involved in this response.

On the other hand, the initial portion of the step response of a system with an even number of RHP zeros exhibits the same even number of inversions before heading in the direction of the final steady-state, but the initial direction is always the same as the direction of the final steady-state.

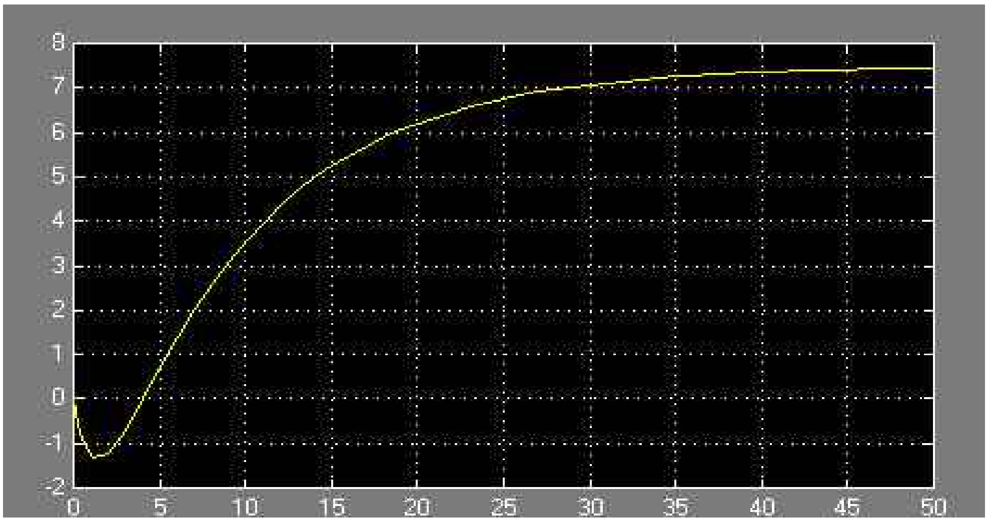

Figure 1.12: Inverse response

12. THE PURE TIME-DELAY PROCESS

In process industries, one often finds systems in which there is a noticeable delay between the instant the input change is implemented and when the effect is observed, with the process output displaying an initial period of no response. Such systems are aptly referred to as time-delay systems, and their importance is underscored by the fact that a substantial number of processes exhibit these delay characteristics.

The process whose transfer function is given by:

$$G(s) = e^{-\alpha s}$$

is known as a pure time-delay process because its response to any input is merely a delayed version of the input. Pure time-delay system is an infinite-order system.

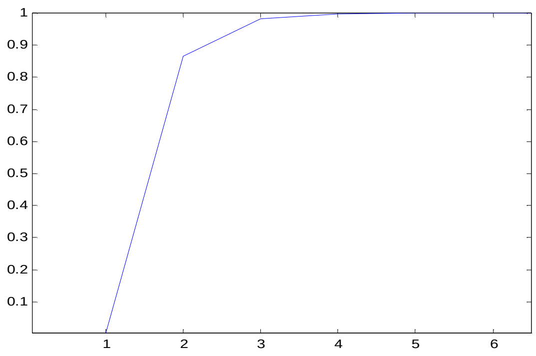

Figure 1.13: Step response of first order process with time-delay = 1

Pure time-delay system is equivalent to an infinite sequence of identical first-order systems in series.

Approximating the behavior of very high order systems with that of low order systems with delays is a common strategy adopted in Process Control practice. This strategy is not only useful for understanding the process but sometimes it is also an important aspect of controller design.

13. ANALYSIS & DESIGN OF ADVANCED CONTROL SYSTEMS

Between the measuring device and the final control elements comes the controller. Its function is to receive the measured output signal and after comparing it with set point to produce the actuating signal in such a way as to return the output to the desired value.

The input to the controller is the error (The difference between SETPOINT and MEASURED OUTPUT SIGNAL), while its output is the actuating signal. The various types of continuous feedback controllers differ in the way they relate ERROR to the ACTUATING SIGNAL.

13.1 Basic Terminology Used for Controllers

13.1.1 Proportional Band (PB)

Characterizes the range over which the error must change in order to drive the actuating signal of the controller over its full range. It is defined as

$$PB = \frac{\text{Maximum range of controller output}}{\text{Maximum range of measured variable}} * (100/Kc)$$

The proportional band is the range of deviations, in percent of scale, that corresponds to the full range of valve opening. Figure 1.14 shows the possible relationship between deviation and valve opening for three different proportional band settings.

Single-loop controllers usually have a proportional band or gain adjustment. Gain is an inverse function of the proportional band, which means the proportional band settings of 20, 100 and 200 % would be equal to gain settings of 5, 1 and 0.5, respectively. The width of the proportional band determines the amount of valve motion for any given change in the process variable. Thus, the rule of thumb is that the wider the proportional band, the smaller the change in valve position for any given change in the process variable.

13.1.2 Proportional Gain (Kc)

The larger the gain Kc, or equivalently, the smaller the proportional band, the higher the sensitivity of controller's actuating signal to deviations will be.

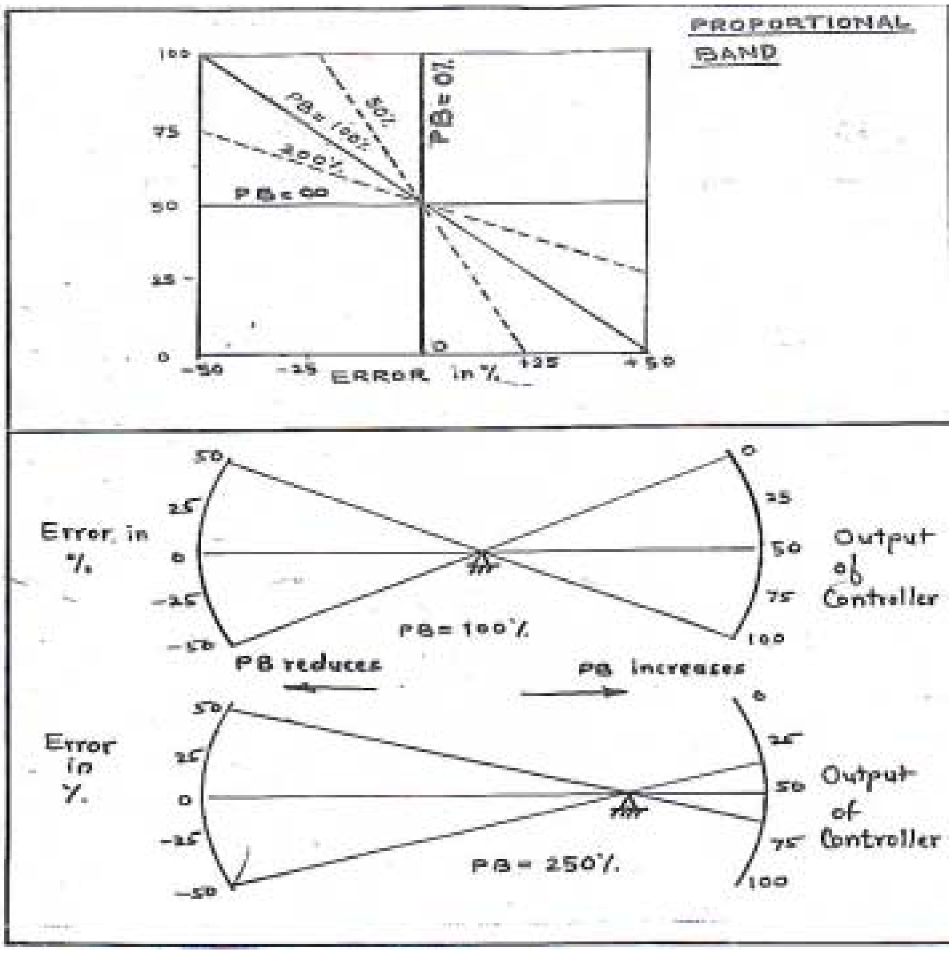

Figure 1.14: Possible Relationship between Deviation and Valve Opening for Three Different Proportional Band Settings

13.2 The Characteristics of P, I, and D Controllers

13.2.1 Proportional Controllers (P)

Proportional only controllers are the simplest controllers with the advantage of only one tuning parameter, Controller gain (or Proportional Band).

A proportional controller (K_p) will have the effects of reducing the rise time and will reduce, but never eliminate, the steady-state error (also called as Offset).

13.2.2 Proportional-Integral Controller (PI)

PI controllers have two tuning parameters: the gain or proportional band, and the reset time or reset rate or the Integral time

An integral control (K_i) will have the effects of eliminating the steady-state error, but it may make the transient response worse.

13.2.3 Proportional-Integral-Derivative Controller (PID)

PID controllers have three tuning parameters: the gain or proportional band, and the reset time or reset rate or the derivative time.

PID controllers are recommended for long time constant loops that are free of noise. A derivative control (K_d) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response.

13.2.4 Proportional- Derivative Controller (PD)

This controller is used in processes where a proportional only controller can be used but some amount of "anticipation" is desired.

A disadvantage of the PD controller is the operation with an offset in the controlled variable. Only the integral action can remove the offset. However, a PD controller can stand higher gain, thus resulting in smaller offset, than a proportional only controller on the same loop.

13.3 Limitations of PID Controllers

- PID controllers are difficult to parameterize and tune 'as-is'
- Cannot handle multivariable systems
- Cannot handle nonlinear and complex systems
- Cannot handle deadtime
- Cannot handle constraints on CVs
- Several extensions developed, but of limited use

13.4 Effect of Changes in Controller Gains

Effects of each of the controller gains (Kp, K_d and K_i) on a closed-loop system are summarized in the table below.

TABLE 1.4: Effect of Controller Gains on Various Parameters

Closed Response	Rise Time	Overshoot	Settling Time	Steady-state error (Offset)
$K_p \uparrow$	Decrease	Increase	Small Change	Decrease
$K_i \uparrow$	Decrease	Increase	Increase	Eliminate
$K_d \uparrow$	Small Change	Decrease	Decrease	Small Change

Note:

These correlations may not be exactly accurate, because K_p, K_i, and K_d are dependent on each other. In fact, changing one of these variables can change the effect of the other two. For this reason, the table should only be used as a reference when one is determining the values of K_p, K_i, and K_d.

13.5 Proportional Control - The "P" in PID

They can move control valves to intermediate positions that are proportional to the deviation from the setpoint. This advantage can also turn into a disadvantage whenever there is a load change. Since there is a fixed relationship between the value of the process variable and the position of the valve, the controller can move the control valve to only one position for any given value of the controlled variable, regardless of the process load.

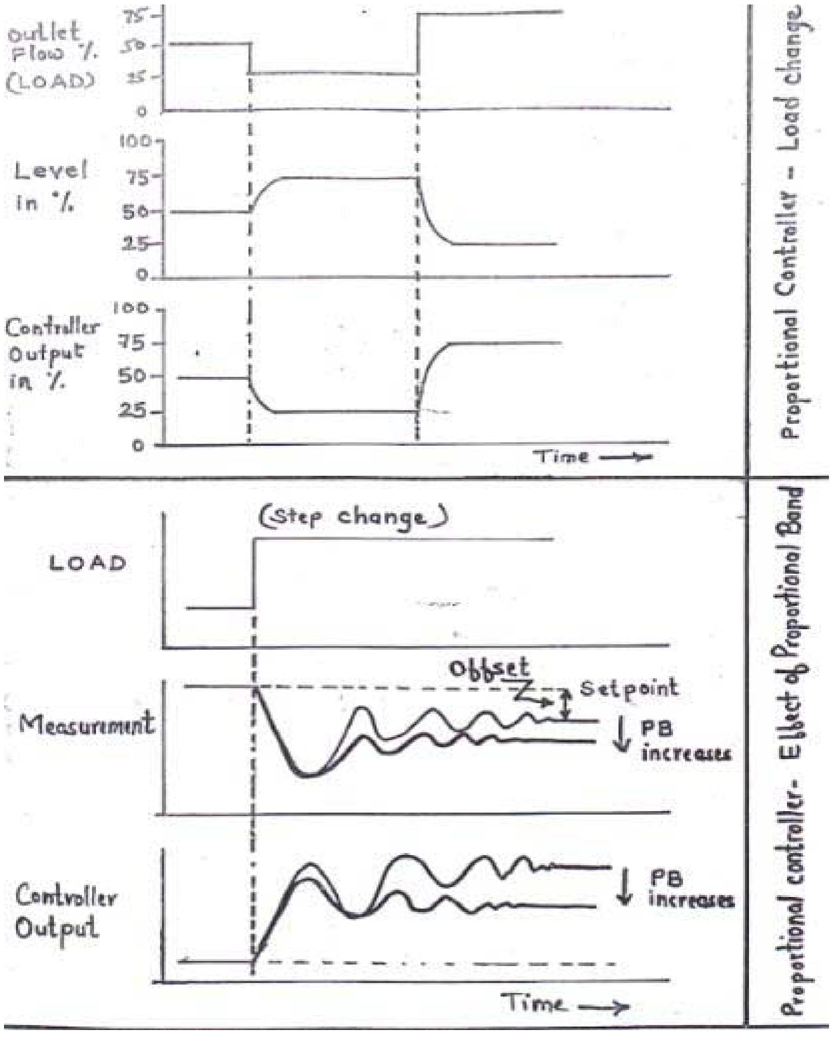

Figure 1.15: Response of proportional action to sudden change in setpoint

13.6 Integral Control = The "I" in PID

Proportional action has no sense of time, whereas integral control action is completely dependent upon time. Integral control action response to the continued existence of deviation such as the offset inherent in a proportional controller. By combining proportional action, with integral action, the controller output will be changed at a steady rate for each value of deviation. In effect, it will continue to change valve position to accommodate load changes as long as there is any deviation at all. The integral action stops when the deviation becomes zero and the valve stays in the position in which the integral action put it.

The actual response of the integral action depends on the characteristics of the proportional control action and the settings of the controller's integral rate adjustments. The integral rate is usually measured in repeats per minutes or sometimes in minutes per repeat. It defines the integral rate as the number of times it repeats the proportional action correction per minute.

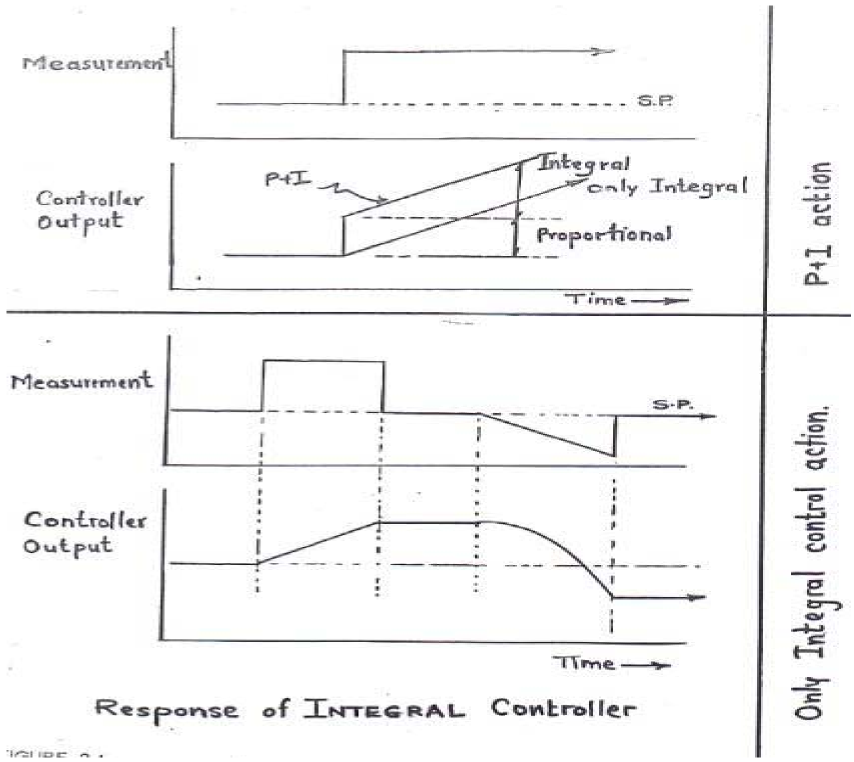

Figure 1.16: Response of Integral Controller

13.7 Derivative Control = the "D" in PID

Derivative action is used only in combination with the proportional or proportional plus integral control action. It responds to changes in the speed and direction of deviation. A constant deviation from a fixed setpoint initiates no response from derivative action. If the deviation starts to change, stops changing or alters its rate of change because of a change in the process variable or the setpoint, the derivative action combines with the proportional action to quicken controller response. It does so by moving the control valve to a position it would have eventually assumed with proportional action only. The result is an extra change in the output that compensates for the unfavorable effect of process of deadtime or transfer lag.

Controllers with derivative control action have built in rate amplitude and a rate time adjustments. Rate time is measured in minutes, and is usually set to compensate for the deadtime that retards proportional control action. The actual effect of the derivative action also depends on the characteristics of proportional control action.

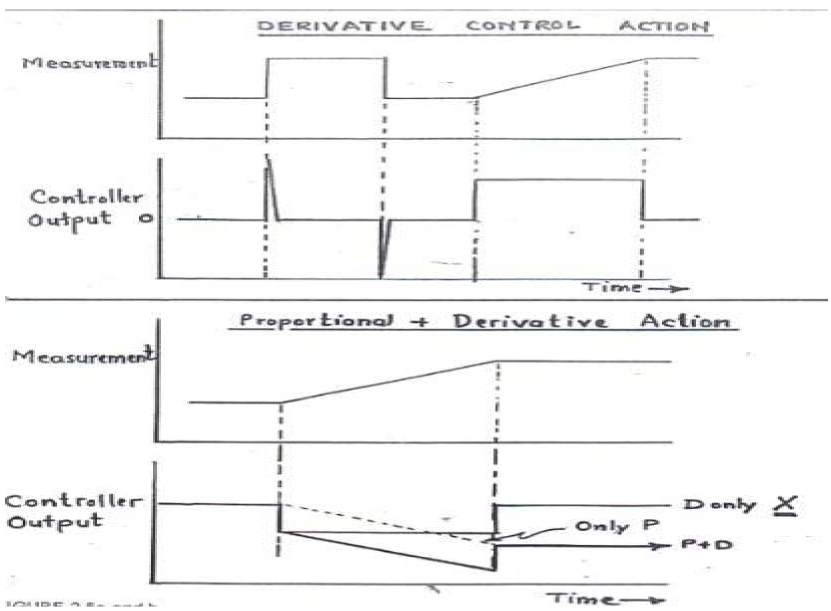

Figure 1.17: The Derivative action

13.8 Reset Windup

When a controller with integral action (PI or PID) sees an error signal for a long period of time, it integrates the error until it reaches a maximum (usually 100 % of scale) or a minimum (usually 0 %). This is called reset windup. Reset windup typically occurs in batch processes, in cascade control, and when a final control element is driven by more than one controller, as in override control schemes. *Cascade control and override control are presented in the Appendix.*

13.9 Tuning of Controllers

After the type of feedback controller has been selected, one still has the problem of deciding what values to use for its adjustable parameters. This is known as the *Controller tuning* problem. There are three general approaches one can use for tuning a controller:

- Use simple criteria such as the one-quarter decay ratio, minimum settling time, minimum largest error, and so on. Such an approach is simple and easily implementable on an actual process. Usually it provides multiple solutions. Additional specifications on the closed-loop performance will then be needed to break the multiplicity and select a single set of values for the adjusted parameters.

- Use time integral performance criteria such as Integral of the square error (ISE), Integral of the absolute value of the error (IAE), or Integral of the time-weighted absolute error (ITAE). This approach is rather cumbersome and relies heavily on the mathematical model (transfer function) of the process. Applied experimentally on an actual process, it is time consuming.

- Use semi-empirical rules, which have been proven in practice.

13.9.1 Ziegler -Nichols (ZN) Closed Loop Tuning

The Ziegler-Nichols Closed Loop method is one of the more common methods used to tune control loops. It was first introduced in a paper published in 1942 by J.G. Ziegler and N.B. Nichols, both of whom at the time worked for Taylor Instrument Companies, Rochester, NY.

To use the method the loop is tested with the controller in automatic. The Closed Loop method determines the gain at which a loop with proportional only control will oscillate, and then derives the controller gain, reset, and derivative values from the gain at which the oscillations are sustained and the period of oscillation at that gain.

The ZN Closed Loop method should produce tuning parameters which will obtain quarter wave decay. This is considered good tuning but is not necessarily optimum tuning.

Steps

- Ensure that the process is lined out with the loop to be tuned in automatic with a gain low enough to prevent oscillation.
- Increase the gain in steps of one-half the previous gain. After each increase, if there is no oscillation change the setpoint slightly in order to trigger any oscillation.
- Adjust the gain so that the oscillation is sustained, that is, continues at the same amplitude. If the oscillation is increasing, decrease the gain slightly. If it is decreasing, increase the gain slightly.
- Make note of the gain, which causes sustained oscillations, and the period of oscillation. These are the **"Ultimate Gain"** (GU) and the **"Ultimate Period"** (PU) respectively.
- Calculate tuning for the following set of equations. Use the set that corresponds to the desired configuration: P only, PI, or PID.

Tuning Equations

- P Only: Gain = 0.5 GU
- PI: Gain = 0.45 GU, Reset = 1.2/PU
- PID: Gain = 0.6 GU, Reset = PU/2, Derivative = PU/8

13.9.2 Process Reaction Curve Method / Cohen-Coon Tuning Method:

This is a popular empirical tuning method developed by Cohen and Coon based on the specific nature of the process curve in the "open-loop" condition.

Steps:

- "Open" the control system by disconnecting the controller from the final control element. Introduce a step change of magnitude A in the input variable that actuates the final control element.
- The response of output signal is recorded. The resulting plot of output versus time must cover the entire Test State.

Cohen and Coon observed that the response of most processing units to an input change, such as the above, had a sigmoidal shape, which can be approximated by the response of a first order system with dead time. Hence,

$$G_{PROCESS}\ (t) = \frac{K}{\tau s + 1} e^{-\theta S}$$

which has three parameters: Static gain K, dead time θ, and the time constant T. From the response, values can be estimated as:

$$K = \frac{\text{Output (at steady state)}}{\text{input (at steady state)}}$$

$$T = \frac{\text{Output (at steady state)}}{\text{the slope of the sigmoid response at the point of inflection}}$$

θ = Time elapsed until the system responded.

Cohen and Coon used the approximate model (i.e. the above equation) and estimated the values of the parameters K, θ and T as indicated above. Then they derived expressions for the "best" controller settings using load changes and various performance criteria. The results of their analysis are summarized below.

For Proportional Controllers (P):

$$K_P = \frac{\tau}{K\ \theta}\left(1 + \frac{\theta}{3\tau}\right)$$

For Proportional-Integral controllers(PI)

$$K_{PI} = \frac{\tau}{K\ \theta}\left(0.9 + \frac{\theta}{12\tau}\right)$$

$$T_{PI} = \theta\ \frac{30 + 3\theta / T}{9 + 20\,\theta / T}$$

For Proportional-Integral-Derivative Controllers (PID)

$$KPID = \frac{\tau}{K\ \theta}\left(\frac{4}{3} + \frac{\theta}{4\tau}\right)$$

$$TIPID = \theta\ \frac{32 + 6\theta / T}{13 + 8\,\theta / T}$$

$$TDPID = \theta\ \frac{4}{11 + 2\,\theta / T}$$

Remarks

The controller settings given by these equations are based on the assumption that the first-order plus dead-time system is a good approximation for the sigmoidal response of the open-loop real process. It is possible, though, that an approximation may be poor. In such case the Cohen-Coon settings should be viewed only as first guesses needing certain online correction.

14. TUNING

The job of the engineer is to design a control system that will maintain the controlled variable at its set point.

Once this is done, he must then tune the controller so that it minimizes the trial-and-error operation required for control.

To do this engineer must know the characteristics, or "personality" of the process to be controlled. Once this "process personality" is known, the engineer can design the control system and obtain the best "controller personality" to match that of the process.

To explain the meaning of personality, let's say you are trying to persuade someone to behave in certain way i.e., to control someone's behavior. You are the controller and someone is the process.

The wisest thing for you to do is to learn that someone's personality and adapt yourself to that personality to do a good job of persuading or controlling. That is what we meant by "tuning the controller".

15. STABILITY

When a process is "disturbed" from an initial steady state, say, by implementing a change in the input forcing function, it will, in general, respond in one of three ways:

Response 1:

Proceed to a new steady state and remain there, or

Response 2:

Fail to attain steady-state conditions because its output grows indefinitely.

Response 3:

Fail to attain steady-state conditions because the process oscillates indefinitely with constant amplitude.

It now seems perfectly logical to consider the process that ultimately settles down after having been disturbed as being "stable" and the one that fails to settle down as being "unstable".

- A system is stable if its output remains bounded for a bounded input.
- A process is said to be unstable if its output becomes larger and larger (either positively or negatively) as time increases.

Most industrial processes are open loop stable, that is, they are stable when not a part of a feedback control loop. This is equivalent to saying that most processes are self-regulating, i.e., the output will move from one steady state to another when driven by changes in its input signals.

A typical example of an open-loop unstable process is an exothermic stirred-tank reactor. This type of reactor sometimes exhibits an unstable operating point where increasing temperature produces an increase in reaction rate with the consequent increase in the rate of heat liberation. This in turn causes a further increase in temperature.

In order for a feedback control loop to be stable, all of the roots of its characteristic equation must be either negative real numbers or complex numbers with negative real parts.

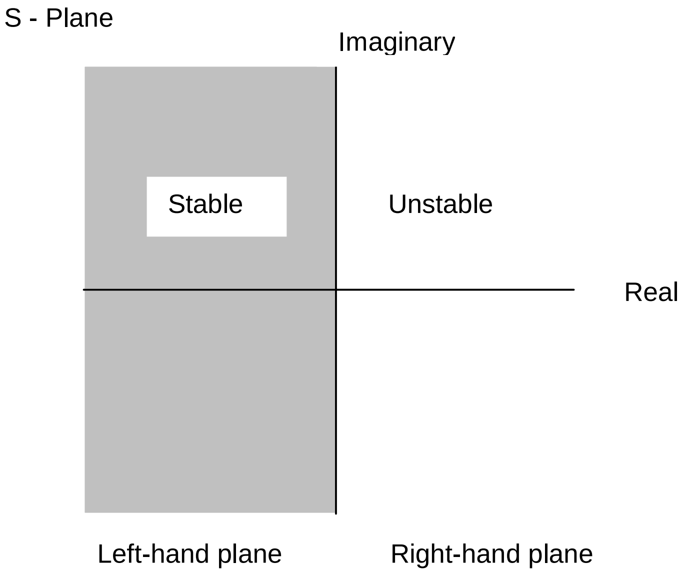

Figure 1.18: Stability Region

In order for a feedback control loop to be stable, all the roots of its characteristic equation must fall on the left-hand half of the S-plane (the "left-hand plane").

15.1 Routh's Test

It is a procedure to determine how many of the roots of a polynomial have positive real parts without finding the roots by iterative techniques. Since the stability of a system requires that none of the roots of its characteristic equation have positive real parts, Routh's test is most useful to determine stability.

- It is a purely algebraic test that tells us how many roots of a polynomial have real parts without calculating the actual values of these roots.
- It is limited to polynomial equations only.

16. DIGITAL CONTROL

Reduced to its most fundamental essence, a controller is no more than a device that, given information about the error signal (ε) from a process, computes the control action required to reduce the observed error, using a predetermined control "law".

Viewed in this light, we see that the classical analog feedback controllers – which operate according to the PID control laws discussed earlier – are just one possible class of controllers; one can see that there are other devices, operating according to other control laws, that can also function as controllers.

The digital computer is perfectly suited to do the job of a controller with greater flexibility and versatility than the classical controllers with the following advantages:

- Data acquisition from the physical process is very easily and rapidly done with the digital computer.
- A tremendous capacity for mass storage (and rapid retrieval) of the collected process information is readily available.
- The control "law" for calculating corrective control action no longer has to be restricted to a hardwired analog circuit (e.g. for PID control) because any control law, no matter how unconventional or complicated, can usually be programmed on a computer.
- The required computations, no matter how complex, can be carried out at relatively high speeds.
- The cost of digital computers and ancillary equipment has reduced drastically in the last few years.

16.1 Computers and Data Acquisition

Computers, by nature, deal only in "digitized" entities: integer numbers. The output signals from a process, however, are usually continuous (e.g. Voltage signals from a thermocouple). Since the computer can only access information in digital form, computer control applications therefore require the continuous process output signal to be converted to digital form.

The "digitization" of a continuous signal is carried out by an analog-to-digital (A/D) converter. The continuous signal, $y(t)$, is sampled at discrete points in time, t_0, t_1, t_2,…., to obtain the sampled data, $y(t_k)$, $k = 0,1,2,3$……, which is then digitized.

As indicated in Figure 1.19, the sampler of the A/D converter consists of a switch that closes after every Δt time units, theoretically for an infinitesimally small period of time, to produce "samples" of y(t) as $y(t_k)$ "spikes." It is customary to refer to Δt, the length of the time interval between each successive sample, as the *sample time* or *sampling period*; naturally, its reciprocal, $1/\Delta t$, is called the *sampling rate*; and multiplying the sampling rate by 2π gives the sampling frequency.

16.2 Computers and Control Action

On the other side of the computer process control coin is the fact that the computer also *gives out* information in digital form, at discrete points in time. This has significant implications on control action implementation, as we know illustrate.

Consider the situation in which the computer gives out control command signals as shown in Figure 1.19.

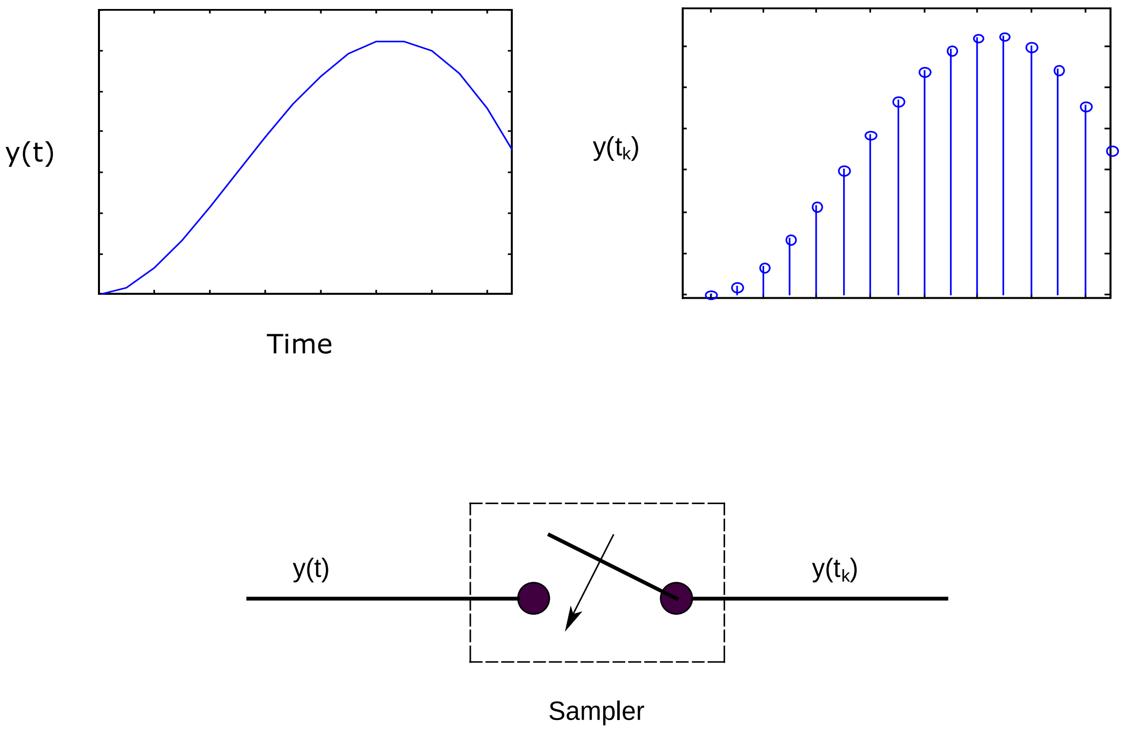

Figure 1.19: A continuous signal discretized

Note that the command signal takes on the value $u(t_k)$ at time instants t_0, t_1, t_2,…., and is zero in between these sample points. In implementing such a control action sequence on a process whose final control element is, for example, an air-to-open control valve, we will find that the valve opens up by an amount dictated by the value that $u(t_k)$ takes at each sampling point, and shuts off completely in between samples. Quite apart from the unusual wear and tear that such control action will have on the valve, it is obvious that the intention is not to have the control valve open up only at sampling points; the intended control action is shown in the dashed line in Figure 1.20.

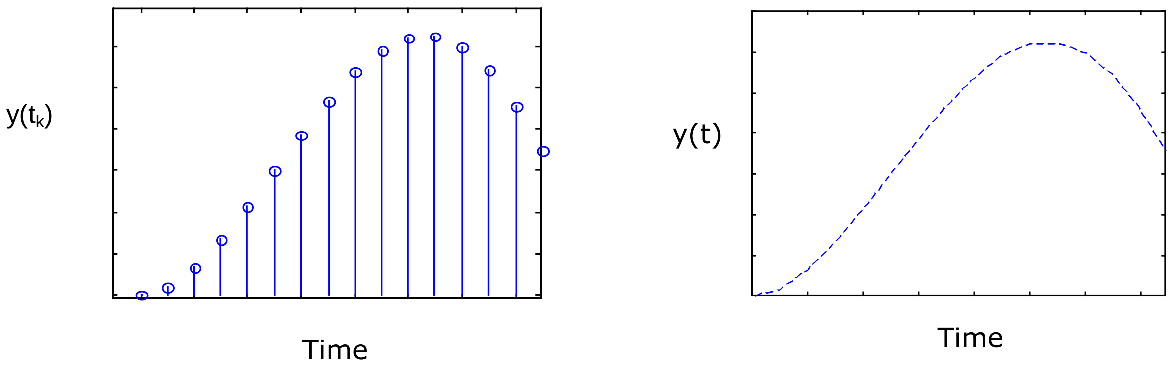

Figure 1.20: A discrete Signal from the Computer and the intended continuous version

Since the computer is incapable of giving out continuous signals, what is required is a means of reconstructing some form of "continuous" signal from these impulses. The device for doing precisely this is known as a digital-to-analog (D/A) converter. The key elements in D/A converters are called ***holds***; they are designed to simply "hold" the previous value of the signal (or its slope, or some other related function), until another sample is made available.

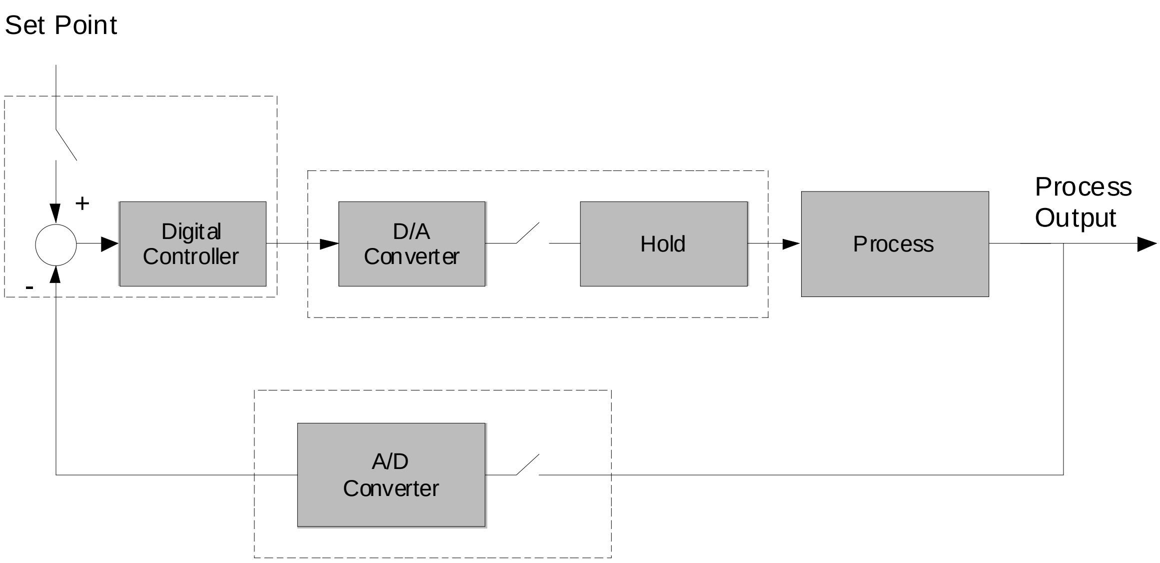

Figure 1.21: Typical Block Diagram for a Computer Control System

The three major issues raised by the use of digital computers for control system implementation may therefore be summarized as follows:

- Sampling (and conditioning) of continuous signals
- Continuous signal reconstruction
- Appropriate mathematical description of sampled-data systems.

16.3 Choosing Sampling Time (Δt)

Let us illustrate the issues involved with choosing Δt by considering the following two extreme situations:

- **Sampling too rapidly:** The sampled signal very closely resembles the continuous signal; but this would obviously require a large number of samples and a large amount of data storage. In addition, this increased workload can limit the number of other loops the computer can service.
- **Sampling too slowly:** In this case, fewer samples will be taken, and as a result, there will be no unusually heavy burden on the computer. However the main problem is that the sampled signal may no longer resemble the original continuous signal. This problem is known as *aliasing*.

Generally sampling time is 1/5 to 1/10 of the dominant time constant of the process.

16.4 Signal conditioning

This usually involves the following:

- Amplification of weak signals
- Noise suppression by filtering
- Possible multiplexing

Multiplexer

To avoid the need for a large number of Analog to Digital converters handling the conversion of a large number of different analog signals, it is common practice to use a multiplexer. This is an electronic switch with several ports, which can serve sequentially several lines carrying analog signals.

Even though the usual practice is for instrumentation engineers to take care of the issue of signal conditioning at the hardware design and selection stage, this only ensures that the signal, that was produced by the measurement device reaches the computer intact. Once the data are in the computer, additional digital filtering may be required to enhance the precision of the measurements. The simplest, and perhaps the most popular, digital filter is the exponential filter which works according to the following equation:

$$\hat{y}(k) = \beta\,\hat{y}(k-1) + (1-\beta)\,y(k)$$

Where

$\hat{y}(k)$ is the filtered value of the signal at the sampling instant k (when t = tk)

$y(k)$ is the measured signal value at the sampling instant k

β is the filter constant $0 < \beta < 1$

This filter is classified as a *low-pass* filter because it allows only the low frequency components of a signal to pass through, the higher frequency components having been substantially reduced. Other types of digital filters are also used in practice. It is important to note that while filters help suppress the effect of high-frequency fluctuations, they may also introduce additional dynamics into the control system, and hence can affect the dynamic behavior of the overall control system.

16.5 Continuous Signal Reconstruction

The first point to note about continuos signal reconstruction is that there is no unique solution to this problem: there are many different ways by which one can make a discrete signal take on a continuous form. Thus depending on what strategy is adopted, several different kinds of "continuous" versions are possible for the *same* discrete signal.

16.6 Holds

The essence of the signal reconstruction problem is really that of connecting discrete points with a curve to give the otherwise discrete signal a semblance of being continuous. From a purely mathematical point of view, it would appear that the best way od oing this is by employing splines or other interpolation devices. This approach is, however, not very practical, for two reasons:

- In practice, the points to be connected by the curve are control commands issued sequentially by the computer. This goes directly against the principles underlying the application of splines, since they are typically used to connect a "static" collection of points, not a set of points made available sequentially.
- Even if the process of connecting points with splines could be made sequential, the effort required to make this possible appears disproportionate to any potential benefits to be realized.

A very simple, and intuitively appealing, approach to this problem is to simply hold the value of the discrete signal constant at its previous value over the sampling interval until the next sampled value is available; the control variables then takes on this new value that is also held over the next sampling interval.

17. DISTRIBUTED CONTROL SYSTEMS (DCS)

For larger processes such as more complex pilot plant and full-scale plants where there can be hundreds of control loops, commercial distributed control systems are often the network of choice. There are many vendors who provide these DCS networks – the largest are Bailey, Foxboro, and Honeywell – with a variety of proprietary features.

The elements of a commercial DCS network are illustrated below.

Connected to process are a large number of local data acquisition and control computers. Each local computer is responsible for certain process measurements and part of the local control action. They report their measurement results and control actions taken to the other computers via the data highway. Although the Figure 1.14 shows only one data highway, in practice there can be several levels of data highways. Those closest to the process handle high raw data traffic to local computers while those farther away from the process deal only with processed data but for a wider audience.

For each data highway, any computer on that highway, in principle, could access any of the data on that highway. The data highway then provides the information to the multidisplays on various operator control panels, sends new data and retrieves historical data from archival storage, and serves as a data link between the main control computer and other parts of the network.

Sitting above the lower part of the DCS network is a supervisory (or host) computer that is responsible for performing many higher level functions. These could include optimization of process operation over varying time horizons (days, weeks, or months), carrying out special control procedures such as plant startup or product grade transitions, and providing feedback on economic performance. The data link between the host and the main control computer is usually much smaller than those on the data highway because the data transfers are much less frequent and are much less voluminous.

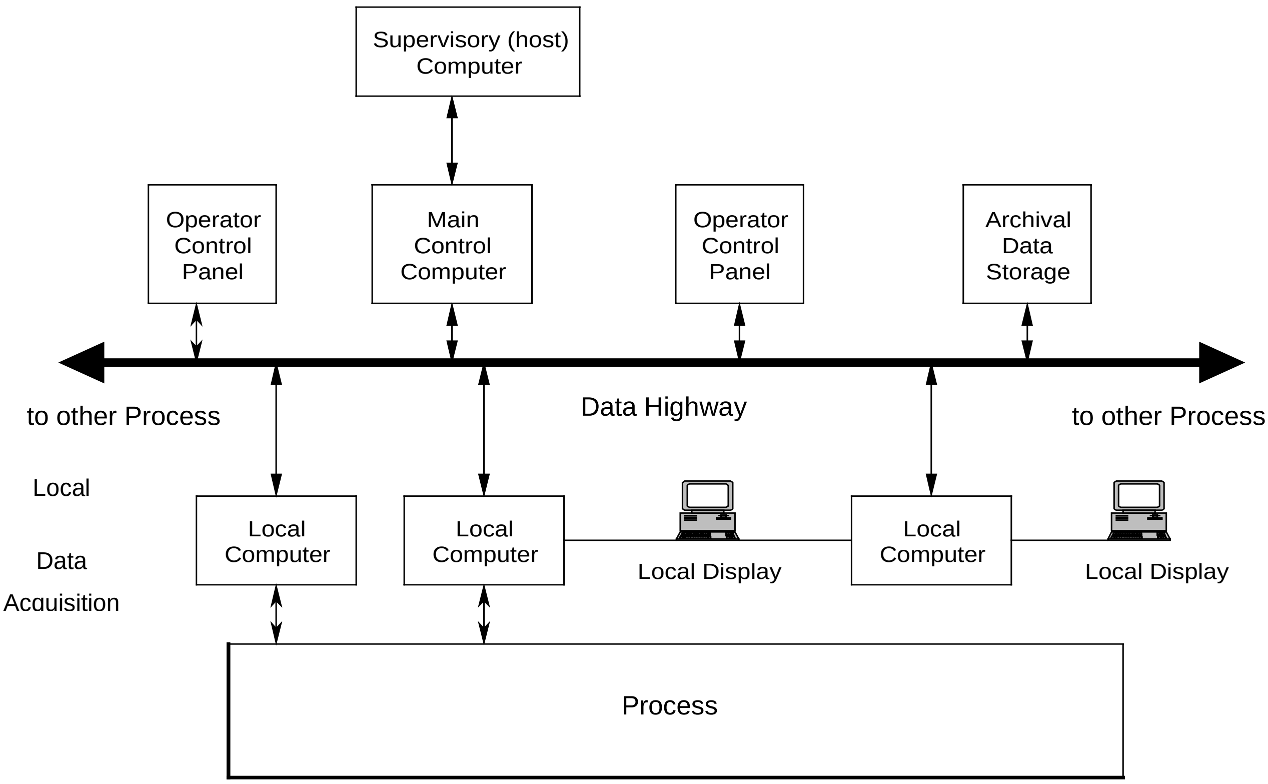

Figure 1.22: The elements of a commercial distributed control system network

The DCS network shown above (Figure 1.22) is very powerful because the engineer or operator has immediate access to a large amount of current information from the data highway and can see displays of past process conditions by calling on archival data storage.

The control engineer can readily install new on-line measurements together with local computers for data acquisition and then use the new data immediately in controlling all the loops of the process. It is possible to change quickly among standard control strategies and readjust controller parameters in software.

Finally, the imaginative control engineer can use the flexible framework to implement quickly his latest controller design ideas on the host computer or even on the main control computer. These are the attributes that will lead to every process of any size having a DCS network in the future.

References for Further Reading

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